REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
10-25-2011

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
09/2008-09/2011

4. TITLE AND SUBTITLE
ULTRAFAST ULTRAINTENSE LASER-MATTER INTERACTIONS- FROM MOLECULES TO METALS

5a. CONTRACT NUMBER
FA9550-08-1-0056

5b. GRANT NUMBER
FA9550-08-1-0056

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Chunlei Guo

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Rochester
275 Hutchinson Road, Rochester, NY 14627

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research

10. SPONSOR/MONITOR'S ACRONYM(S)
NE

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-OSR-VA-TR-2012-0645

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution A

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This project aims at exploring a number of exciting new research directions in studying molecules and metals subject to ultrafast ultrainense laser irradiation. In studying molecules in intense laser fields, we have made progresses in extending the study of multielectron effects to tri-atomic molecules and provided a deeper understanding of the intense field behaviors. In the study of metals, we recently showed that a piece of shiny metal can be transformed to a nearly perfect light absorber following intense femtosecond laser pulse treatment. This project allowed us to extend our understanding of the fundamental mechanisms to a much deeper level. Furthermore, we have made a number of discoveries from making much brighter light sources to superwicking materials.

15. SUBJECT TERMS
Multielectron effects, atoms and molecules, metals, intense laser fields

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Chunlei Guo
U	U	U	UU		19b. TELEPHONE NUMBER *(Include area code)* 585-275-2134

Final Report to AFOSR

PROJECT TITLE

ULTRAFAST ULTRAINTENSE LASER-MATTER INTERACTIONS- FROM MOLECULES TO METALS

Contract Number
FA9550-08-1-0056

Submitted by

Chunlei Guo

The Institute of Optics
University of Rochester
Rochester, NY 14627

Phone: (585) 275-2134
Fax: (585) 244-4936
email: guo@optics.rochester.edu

Submitted to

Atomic and Molecular Physics Program
Air Force Office of Scientific Research

Abstract

This project aims at exploring a number of exciting new research directions in studying molecules and metals subject to ultrafast ultrainense laser irradiation. In studying molecules in intense laser fields, we have made progresses in extending the study of multielectron effects to tri-atomic molecules and provided a greater understanding of the intense field behaviors. In the study of metals, we recently showed that a piece of shiny metal can be transformed to a nearly perfect light absorber following intense femtosecond laser pulse treatment. This project provided us a greater understanding of the fundamental mechanisms of metal darkening. Furthermore, we have made a number of discoveries from making much brighter light sources to superwicking materials. This research leads to about 40 refereed journal publications during the project period.

Some inventions

One example is that we created a technique that allows us to transform highly reflective metals to reflect only a certain color of light, creating the so-called “colored metal”. This research is a significant step forward by us earlier in rendering highly reflective metals totally absorptive. The darkened and colored metals have many applications such as making better sensors, detectors, solar energy collectors, laser marking, and even improved stealth technology. The colored metal technique developed has attracted an extensive amount of media attention and is covered by hundreds of media outlets, including The New York Times, MSNBC, Science, and Nature Magazines. Besides the metal colorizing technique, we have also made progresses in a number of other research areas, including creating unique surface structures on metals and studying its mechanisms, understanding surface plasmon excitation on structured metal surfaces, enhancing electron emission following laser light excitation, and understanding wavelength effects in strong-field ionization in atoms and molecules.

More recently, we created a technique that makes incandescent lamps glow much brighter, and this work was featured twice in the New York Times and numerous other news media. Furthermore, we have also created a technique that transforms metal surface to superhydrophilic and renders liquids to run uphill along the surface. This liquid work was also extensively covered by news media. Besides these works, we have also made progresses in a number of other areas, including enhancing light absorption over a superbroad wavelength region, improving our understanding of nanostructural formation on metals, enhancing electron emission following laser light excitation, and understanding multiple charged molecular ionization in strong laser fields.

Refereed Journal Publicatoins

1. Making superwetting human enamel and dentin surfaces for enhanced adhesion
   A.Y. Vorobyev and C. Guo, Appl. Phys. Lett. (in press, 2011).
2. Dissociation of doubly and triply charged N_2 in strong laser fields
   W. Lai, L. Pei, and C. Guo, Phys. Rev. A (in press, 2011).
3. Polarization and angular effects of femtosecond laser-induced nanostructure-covered large scale waves on metals, T.Y. Hwang and C. Guo, J. Appl. Phys. (in press, 2011).
4. Femtosecond laser-induced blazed periodic grooves on metals
   T.Y. Hwang and C. Guo, Opt. Lett. **36**, 2575 (2011).
5. Reflection of femtosecond laser light in multipulse ablation of metals
   A.Y. Vorobyev and C. Guo, J. Appl. Phys. **110**, 043102 (2011).
6. Antireflecton effect of femtosecond laser-induced periodic surface structures on silicon
   A.Y. Vorobyev and C. Guo, Opt. Express **19**, A1031 (2011).
7. Enhanced efficency of solar-driven thermoelectric generator with femtosecond laser-textured metals
   T.Y. Hwang, A.Y. Vorobyev, and C. Guo, Opt. Express **19**, A824 (2011).
8. Brighter light sources from black metal: significant increase in emission efficiency of incandescent light sources: Reply, A. Y. Vorobyev and C. Guo, Phys. Rev. Lett. **106**, 249402 (2011).
9. Optical and Wetting Properties of Femtosecond Laser Nanostructured Materials
   A.Y. Vorobyev and C. Guo, J. of Nano Research **14**, 57 (2011).
10. Observation of femtosecond laser-induced nanostructure-covered large scale waves on metals
    T.Y. Hwang and C. Guo, J. Appl. Phys. **109**, 083521 (2011).
11. Thermal Response and Optical Absorptance of Metals under Femtosecond Laser Irradiation
    A.Y. Vorobyev and C. Guo, J. of Natural Science **3**, 488 (2011).
12. Direct creation of black silicon using femtosecond laser pulses
    A.Y. Vorobyev and C. Guo, Appl. Surf. Sci. **257**, 7291 (2011).
13. Femtosecond Laser Machining of Electrospun Membranes
    Y. Wu, A.Y. Vorobyev, R.L. Clark, **C. Guo**, Appl. Surf. Sci. **257**, 2432 (2011).
14. Laser makes silicon superwicking
    A.Y. Vorobyev and C. Guo, *Optics & Photonics News* **21**(12), 38 (2010).
15. Water runs uphill on glass
    A.Y. Vorobyev and C. Guo, J. Appl. Phys. **108**, 123512 (2010).
16. Angular effects of nanostructure-covered femtosecond laser induced periodic surface structures on metals, T.Y. Hwang and C. Guo, J. Appl. Phys. **108**, 073523 (2010).
17. Nonsequential double ionization of triatomic molecules in strong laser fields
    L. Pei and C. Guo, Phys. Rev. A (Rapid Comm.) **82**, 021401(R) (2010).
18. Surface-plasmon-enhanced photoelectron emission (**Invited**)
    C. Guo, SPIE Newsroom. DOI: 10.1117/2.1201005.002935 (2010)
19. Laser turns silicon superwicking
    A. Y. Vorobyev and C. Guo, Optics Express **18**, 6455 (2010).
20. Metallic light absorbers produced by femtosecond laser pulses
    A. Y. Vorobyev and C. Guo, Advances in Mechanical Engineering **2010**, 452749 (2010).
21. Ultrafast dynamics of femtosecond laser-induced nanostructure formation on metals
    T.Y. Hwang, A.Y. Vorobyev, and C. Guo, Appl. Phys. Lett. **95**, 123111 (2009).
22. Towards the THz black metamaterial
    A.Y. Vorobyev, A. N. Topkov, O. V. Gurin, V. A. Svich, C. Guo, Appl. Phys. Lett. **95**, 21106 (2009).

23. Brighter light sources from black metal: significant increase in emission efficiency of incandescent light sources, A. Y. Vorobyev and C. Guo, Phys. Rev. Lett. **102**, 234301 (2009).
24. High-current, relativistic, electron-beam transport studies in metals using high-resolution, coherent transition radiation imaging, M. Storm, A.A. Solodov, J.F. Myatt, D.D. Meyerhofer, C. Stoeck, R. Betti, P.M. Nilson, T.C. Sangster, W. Theobald, and C. Guo, Phys. Rev. Lett. **102**, 235004 (2009).
25. Femtosecond laser-induced surface structures on platinum and their effects on surface wettability and fibroblast cell prolifereation, E. Fadeeva, S. Schlie, J. Koch, B. N. Chichkov, A. Y. Vorobyev, and C. Guo, Contact Angle, Wettability and Adhesion, vol **6**, 163 (Koninklijke Brill NV, Leiden, 2009).
26. Reply brighter light sources from the black metal
A.Y. Vorobyev, V.S. Makin, and C. Guo, Phys. Rev. Lett. **103**, 269402 (2009).
27. Metal pumps liquid uphill
A. Y. Vorobyev and C. Guo, Appl. Phys. Lett. **94**, 224102 (2009).
28. Triple-ionization-induced dissociation of molecules in strong laser fields **(Invited Paper)**
C. Guo**,** Laser Physics Journal **19**, 1635 (2009).
29. Surface-plasmon-enhanced photoelectron emission from nanostructure-covered periodic grooves on metals, T.Y. Hwang, A.Y. Vorobyev, and C. Guo, Phys. Rev. B **79**, 085425 (2009).
30. Colorizing metals with femtosecond laser pulses
A.Y. Vorobyev and C. Guo, *Optics & Photonics News* **19**(12), 30 (2008).
31. Femtosecond laser-induced periodic surface structure formation on tungsten
A.Y. Vorobyev and C. Guo, J. Appl. Phys. **104**, 063523 (2008).
32. A high-resolution coherent transition radiation diagnostic for laser-produced electron transport studies (**invited**) M. Storm, I. A. Begishev, R. J. Brown, C. Guo, D. D. Meyerhofer, C. Mileham, J. F. Myatt, P. M. Nilson, T. C. Sangster, C. Stoeckl, W. Theobald, and J. D. Zuegel, Review of Scientific Instruments, **79**, 10F503 (2008). (Seleted into November 2008 issue of Virtual Journal of Ultrafast Science).
33. Femtosecond laser blackening of platinum
A.Y. Vorobyev and C. Guo, J. Appl. Phys. **104**, 053516 (2008).
34. Modeling of residual thermal effect in femtosecond laser ablation of metals: role of a gas environment
N.M. Bulgakova, V.P. Zhukov, A.Y. Vorobyev and C. Guo, Appl. Phys. A **92**, 883 (2008).
35. Dissipative nanostructures and Feigenhaum's universality in the "metal-high-power ultrashort-pulsed polarized radiation" nonequilibrium nonlinear dynamical system
V.S. Makin, R.S. Makin, A.Y. Vorobyev, and C. Guo, Tech. Phys. Lett. **34**, 387 (2008).
36. Spectral and polarization responses of femtosecond laser-induced periodic surface structures on metals
A. Y. Vorobyev and C. Guo, J. Appl. Phys. **103**, 043513 (2008).
37. Colorizing metals with femtosecond laser pulses
A. Y. Vorobyev and C. Guo, Appl. Phys. Lett. **92**, 041914 (2008).
38. Wavelength effects on strong-field single electron ionization
J. Wu and C. Guo, Adv. Studies in Theo. Phys. **2**, 271 (2008).
39. Dissipative nanostructures and Feigenhaum universality in nonlinear dynamic system metal-powerful polarized ultrashort-pulse radiation
V.S. Makin, R.S. Makin, A.Y. Vorobyev, and C. Guo, Pis'ma v JTF **34**, 55 (2008).

Main Personnel involved in this project:

Graduate students: Taek Yong Hwang, Alan Heins, and Wei Lai
Postdoctoral Associate: Anatoliy Vorobyev